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14. ABSTRACT The long-term goal of this project is to better understand the general problem of ocean-atmosphere interaction on small space and time scales. The present study has focused on gaining a better understanding the coupled response to small-scale atmospheric jets and oceanic surface fronts that are commonly observed near orographic features such as islands and mountain passes. The atmospheric response to sharp SST gradients has been explored in the strong wind regime, defined as U/fL>1, where U is the wind speed, f is the Coriolis parameter, and L is the ocean front width. Adjustments to the atmospheric boundary layer thickness, surface wind speed, and momentum balances are studied for both cold to warm and warm to cold winds. In a second study, it is shown that this feedback between ocean SST and surface winds can either enhance or reduce the growth rate and wavelengths of baroclinically unstable waves in the ocean, depending on wind direction. This coupling is most effective for low latitude, strongly stratified flows.

15. SUBJECT TERMS
air-sea exchange, atmospheric boundary layers, ocean fronts

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Final Report

The Coupled Ocean-Atmosphere Response to Small-Scale Atmospheric Jets

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LONG TERM GOALS

The long-term goal of this project is to better understand the general problem of ocean-atmosphere interaction on small space and time scales.

OBJECTIVES

The objective of this work is to better understand the coupled response to small-scale atmospheric jets that are commonly observed near orographic features such as islands and mountain passes. The initial focus will be to determine how the atmosphere forces, and adjusts to, sharp gradients in sea surface temperature (SST), and to look for a positive feedback between sea surface temperature and surface winds that may drive resonant modes of variability. Areas of focus include: oceanic frontogenesis; atmospheric boundary layer turbulence, surface wind stress (curl and divergence); boundary layer thickness; mesoscale and sub-mesoscale variability.

APPROACH

The approach is to apply the fully coupled ONR COAMPS model (with the coupling scheme developed by Skillingstad and Samelson at Oregon State University) to a series of idealized experiments. The initial calculations have focused on the response of the lower atmosphere to SST fronts for both along-front and cross-front winds. The response of the ocean SST front to the changes in the atmospheric boundary layer are also explored for along-front and cross-front winds using both analytic and numerical models.

WORK COMPLETED

The coupled COAMPS model has been set up on the PIs local Linux cluster and two series of coupled runs have been completed. The first considers the coupling between the

atmosphere and upper ocean for along-front winds. The analysis of these model runs has been carried out together with Dr. Leif Thomas and makes use of a modification of his previous 2-D analytic approach to account for a simple ocean/atmosphere coupling. A second series of coupled calculations have been carried out for cross-front winds in which the focus is on the dynamics and thermodynamics of the air-sea coupling in the atmospheric boundary layer. Winds from cold to warm SST and warm to cold SST have been considered.

A separate study on the ocean response to SST/wind coupling that makes use of both analytic and the ROMS ocean model has also been completed.

RESULTS

The analytic and ocean-only model calculations of along-front winds have identified a new mode of variability that arises as a result of a parameterization of the feedback between SST and surface wind. Uncoupled calculations with uniform wind stress show the development of spontaneous modes of variability that do not propagate and have spatial scales of O(5 km). With the simple coupling, the dominant mode of variability is of smaller spatial scale, O(2 km), propagates laterally at a rate of several cm/s, and has a frequency near f. However, this mode of variability is not likely to be important for realistic coupling parameters.

The fully coupled COAMPS model has been run for cross-front winds to better understand the coupling dynamics, with a focus on mid-latitude fronts and strong atmospheric winds ($U>Lf$, where U is the atmospheric wind speed, L is the frontal width, and f is the Coriolis parameter). It was found that there is a positive correlation between SST and surface wind anomaly of strength consistent with observations. The coupling is relative insensitive to details of the boundary layer physics provided that mixing increases with the flux Richardson number. The coupling strength is most sensitive to the background wind strength, increasing quadratically with the wind speed. For mid-latitude fronts with moderate to strong cross front winds, the Coriolis term is primarily responsible for the acceleration or deceleration of the cross front winds. Inertial lee waves and a shallow internal boundary layer are found when winds blow from warm to cold water (Figure 1). For winds from cold to warm water, there is a rapid enhancement of turbulent mixing throughout the boundary layer, a deepening of the boundary layer thickness, and a transfer of momentum between the along-front and cross-front winds.

Using a simple analytic model and supporting numerical model calculations, it was found that this air-sea coupling can significantly impact the evolution of the ocean circulation and SST through a positive feedback with growing baroclinic waves in the ocean (Figure 2). For winds from the warm to cold side of the ocean front, the impact of SST on surface winds, and thus the Ekman pumping velocity in the ocean, is such that baroclinic instability is enhanced and the wavelength of the most unstable wave increases. For atmospheric winds from the cold to warm side of the front the growth rate and wavelength are both decreased. This mechanism is most effective at low latitudes and for strongly stratified ocean flows.

IMPACTS/APPLICATION

These results identify several important features of the coupling between the ocean and atmosphere on spatial scales of the oceanic deformation radius, which is typically unresolved in many atmospheric models. In certain circumstances, it will be necessary to represent the coupling in order to more accurately model the growth and evolution of waves in the ocean. The results of the analytic model identify where this effect is likely to be important. The results from the fully coupled COAMPS model indicate that the evolution of the surface winds in the atmosphere are subject to distinct dynamics in the vicinity of ocean fronts on spatial scales of 1-10 km. In order to correctly model and predict the surface winds (and hence surface waves), one must properly represent the transition region around the front as well as the turbulent boundary layer upwind of the front, which plays a key role in the adjustment over warm water.

RELATED PROJECTS

This study is closely related to the joint ONR/Taiwan Windy Islands Soliton Experiment/ Variability Northern South China Sea (WISE/VANS) program. I have also been in discussions with Glen Gawarkiewicz and Mike Caruso on their analysis of wind data and oceanic variability in the ONR ASIAEX (Asia Seas International Acoustics Experiment) volume interactions program in the South China Sea and with Dr. Julie Pullen at the Naval Postgraduate School about related work she is doing on the coupling between the ocean and atmosphere on small scales.

PUBLICATIONS

Spall, M. A., 2007. Effect of wind stress / sea surface temperature coupling on baroclinic instability in the ocean. *J. Phys. Oceanogr.*, in press.

Spall, M. A., 2007. Mid-latitude wind stress / sea surface temperature coupling in the vicinity of oceanic fronts. *J. Climate*, in press.

Small, R. J., S. deSzoeke, S. P. Xie, L. O'Neill, H. Seo, Q. Song, P. Cornillon, M. Spall, and S. Minobe, 2007. Air-sea interaction over ocean fronts and eddies. *Dyn. Atmos. Oceans*, submitted.

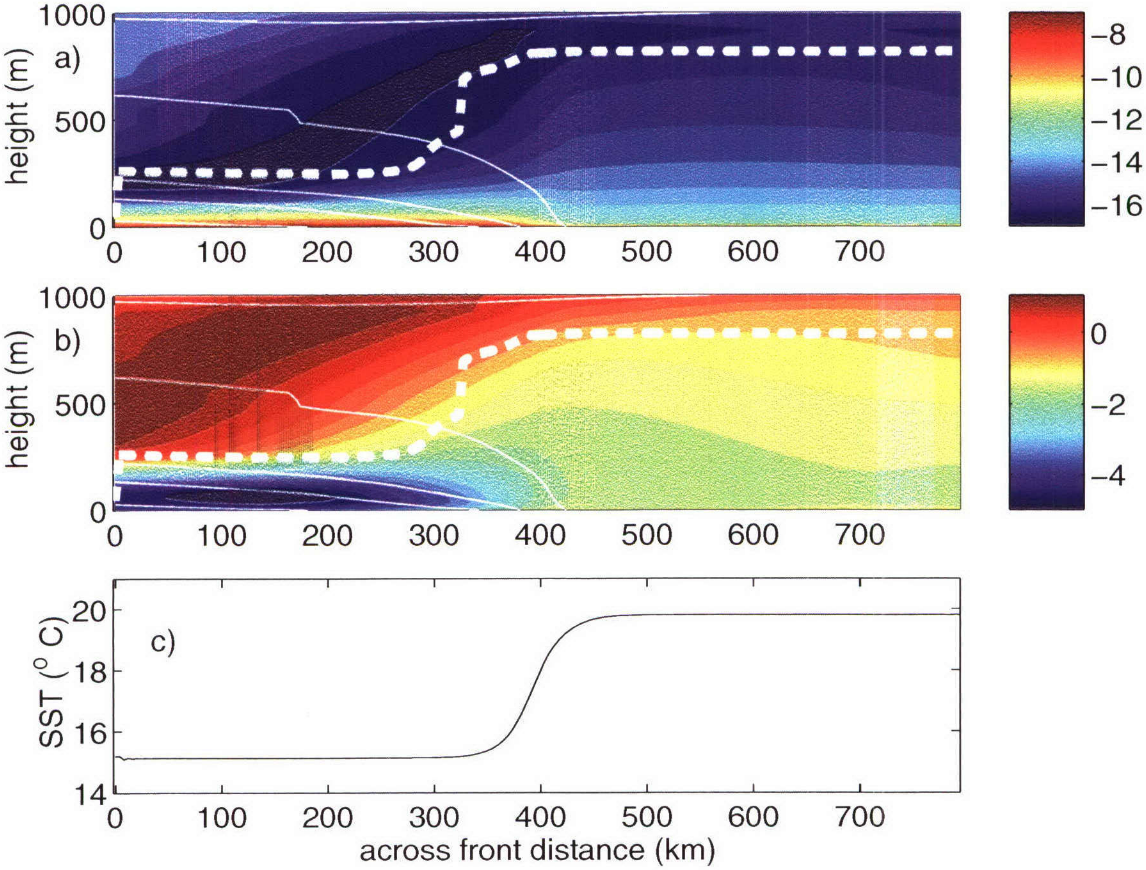

Figure 1: Zonal sections of a) zonal wind and b) meridional wind (colors, units $m\ s^{-1}$) for the case of atmospheric flow from the warm side to the cold side of the front (right to left). Thin white contours are of potential temperature (contour interval 1° C) and the white dashed line is the top of the planetary boundary layer. c) Sea surface temperature.

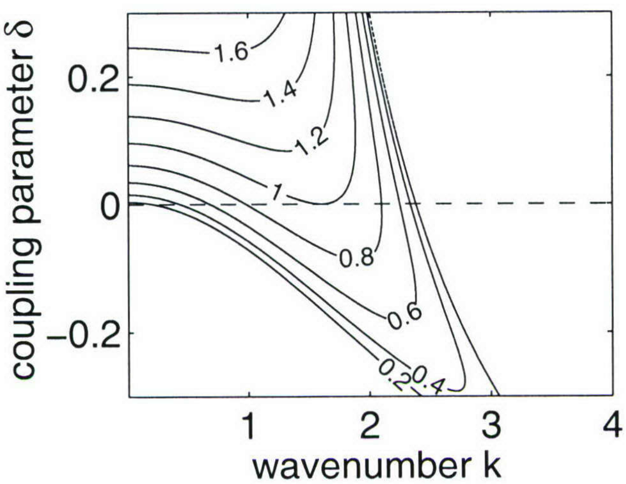

Figure 2: Theoretical growth rate (normalized by the maximum growth rate for the uncoupled Eady problem) as a function of the wavenumber k and a coupling parameter δ. For winds from warm to cold, $\delta > 0$ while for winds from cold to warm $\delta < 0$. Typical values of δ range from 0.01 for strong separated western boundary currents to 0.25 for shallow shelf break fronts or low-latitude zonal currents.